Scanable sparse antenna array.

TECHNICAL FIELD

The present invention relates to an antenna array presenting a sparse antenna design, which also provides scanning with reduced grating lobes.

BACKGROUND

The demand for increased capacity in the area covering communication networks can be solved by the introduction of array antennas. These antennas are arrays of radiating elements that can create one or more narrow beams in the azimuth plane. A narrow beam is directed or selected towards the client of interest, which leads to a reduced interference in the network and thereby increased capacity. In U.S. Patent No. 6,509,881 an interleaved single aperture simultaneous Rx/Tx antenna is disclosed.

A number of simultaneous fixed scanned beams may be generated in the azimuth plane by means of a Butler matrix connected to the antenna columns. The antenna element spacing is determined by the maximum scan angle as the creation of interference lobes due to repeated constructive adding of the phases (also referred to as grating lobes) must be considered. In order to scan a phased array antenna, the element positions must be small enough to avoid grating lobes. For an element distance of 1 λ the grating lobe will appear at the edge of the visible space (non-scanning condition). If the beam then is scanned off boresight, the grating beam will move into the visible space.

Thus, a problem in designing antennas is that the radiating elements in an array antenna have to be spaced less than one wavelength apart in order not to generate troublesome grating (secondary) lobes and in the case of a scanned beam, the spacing has to be further reduced. In the limit case when the main beam is scanned to very large angles (as in the case of an adaptive antenna for mobile communications base stations), the element separation needs to be reduced to half a wavelength or less to avoid generation of

grating lobes within visible space. Thus it can as a general rule be established that an antenna array with a fixed lobe should normally have an element distance of less than 1 wavelength while an antenna array with a scanable lobe should normally have an element distance of less than half a wavelength for obtaining a proper scanning angle range.

As disclosed in U.S. Patent No. 6,351,243, radiating elements in an array antenna are often placed in a regular rectangular grid as illustrated in Figure 1. The element spacing is denoted d_x along the x-axis and d_y along the y-axis. The beam directions are found by transforming from element space to beam space. The corresponding beam space for the antenna illustrated in Figure 1 is found in Figure 2.

In this case the main beam is pointing in the direction along the antenna normal. The beams outside the visible space (i.e. outside the unit circle) constitute grating lobes and they do not appear in visible space as long as the beam is not scanned and the element spacing is less than one wavelength along both axes ($\lambda/d_x > 1$ and $\lambda/d_y > 1$). For a large array, the number of radiating elements in the rectangular arranged grid is approximately given by $N_R = A/(d_x d_y)$, where A is the area of the antenna aperture.

When the main beam is scanned along the x-axis, all beams in beam space move in the positive direction by an amount, which equals a function expressed as sinus of the scan (radiating) angle. For each horizontal row in a one-dimensional scan in the x-direction we can express secondary maxima or grating lobes as

$$x_m = \sin(\theta_s) + m \cdot \frac{\lambda}{d_x}, \qquad m = \pm 1, \pm 2, \ldots$$

wherein x_m is the position of lobe m, θ_s is the scan angle relative to the normal of the array and d_x is the distance between the elements in the horizontal plane. As the distance between lobes here is λ/d_x it will be

realised that the largest element distance for a scan angle producing no grating lobes within the visible region is

$$\frac{d}{\lambda} < \frac{1}{1+\sin(\theta_{max})}$$

In a case illustrated in Figure 3, a second beam (grating lobe) enters visible space in addition to the main beam. This may be avoided by reducing the element spacing along the x-axis. When the element spacing is less than half a wavelength (i.e. $\lambda/d_x > 2$), no grating lobe will enter visible space independent of scan angle, since $|\sin(\theta)| \leq 1$.

Radiating elements placed in an equilateral triangular grid are shown in Figure 4. The vertical element spacing is defined as d_y. A corresponding beam space is illustrated in Figure 5. The element spacing must not be greater than $1/\sqrt{3}$ wavelengths (i.e. a maximum value of d_y is about 0.58 wavelengths) along the y-axis (and $2d_x$ is one wavelength along the x-axis [equal to $d_y\sqrt{3} = 0.58\cdot\lambda\cdot\sqrt{3} = \lambda$]) to avoid generating grating lobes for any scan angle. Thus the optimum element spacing, d_y, in an equilateral triangular grid of radiating elements is $1/\sqrt{3}$ wavelengths. For a large array, the number of radiating elements in the triangular arranged grid is approximately given by $N_T = A/(2d_xd_y)$. (Also see reference E. D. Sharp mentioned above.) A reduction of $(N_R-N_T)/N_R = 13$ % is obtainable for the equilateral triangular grid compared to the square grid assuming the same grating lobe free scan volume. ($N_T = 4A/\lambda^2$ and $N_R = 2A\sqrt{3}/\lambda^2$.)

However there is still a demand for an optimisation of the radiating grid in an array antenna for obtaining a scanning sparse antenna array, which provides a further suppressing of grating lobes within visible space.

SUMMARY

The present invention discloses a sparse array antenna comprising series-fed antenna array columns (wave-guides or other types of transmission lines forming columns of radiator elements) tuned to a respective transmit and

receive frequency. Transmitting and receiving radiation elements are formed with an equal distance between each transmitting radiator element and each receiving radiator element being centred on a symmetry line to form a symmetric interleaved transmit/receive array. The receiving array columns will operate as parasitic elements in a transmit mode and the transmitting array columns will operating as parasitic elements in a receive mode and thereby reduce grating lobes entering visual space particularly when scanning the main radiation lobe off from a boresight direction. Generally the distances between each array column in the transmitting array and each array column in the receiving array are increased to be of the order of one wavelength (λ) for forming a sparse array.

SHORT DESCRIPTION OF THE DRAWINGS

The present invention, together with further objects and advantages thereof, may best be understood by making reference to the following description taken together with the accompanying drawings, in which:

FIG. 1 illustrates an antenna having radiating elements placed in a rectangular grid;

FIG. 2 illustrates beam space for an array demonstrated in Figure 1;

FIG. 3 illustrates the beam space for the antenna illustrated in Figure 1 when the main beam is scanned along the x-axis;

FIG. 4 illustrates an antenna having radiating elements in an equilateral triangular grid;

FIG. 5 illustrates the beam space for an equilateral triangular grid with no grating lobes in visible space;

FIG. 6 illustrates a set of wave-guides for Tx and Rx arranged symmetrically around a line through the centre of each wave-guide;

FIG. 7 illustrates radiation pattern for Test wave-guide, Rx-feed, f=5.671 GHz;

FIG. 8 illustrates radiation pattern for the Test wave-guide, Rx-feed, f=5.671 GHz and Tx antenna element excitations cleared;

FIG. 9 illustrates radiation pattern for the Test wave-guide, Tx-feed, f=5.538 GHz;

FIG. 10 illustrates radiation pattern for the Test wave-guide, Tx-feed, f=5.538 GHz and Rx antenna element excitations cleared;

FIG. 11 illustrates radiation pattern for four Rx-wave-guides with/without passive, interleaved Tx wave-guides, f=5.671 GHz, E-plane, Scan=0°;

FIG. 12 illustrates radiation pattern for four Rx-wave-guides with/without passive, interleaved Tx wave-guides, f=5.671 GHz, E-plane, Scan=10°; and

FIG. 13 illustrates radiation pattern for four Rx-wave-guides with/without passive, interleaved Tx wave-guides, f=5.671 GHz, E-plane, Scan=20°.

DETAILED DESCRIPTION OF THE INVENTION

For describing the present inventive concept a 2 (Rx) + 2 (Tx) wave-guide test model will be described. The goal is then to demonstrate the performance of an interleaved antenna and the correspondence to simulated results. The design of this test model will be described.

The Test model centre frequencies were chosen to be:

f_{RX} = 5.671 GHz

f_{TX} = 5.538 GHz

The slot length and displacement for the slots were calculated using an analysis program for wave-guide slit antennas. The slot length and displacement were set to be equal for all slots within each frequency band function.

The slot parameters were changed and analysed until the input impedance of each wave-guide was matched. The two unexcited wave-guides were also present in the calculation.

The final design parameters are shown below:

f_{RX} = 5.671 GHz (centre frequency)

f_{TX} = 5.538 GHz

λ_{g_Rx} = 82.84 mm (guide wavelength)

λ_{g_Tx} = 87.99 mm

$dx_{Rx} = \lambda_{g\_Rx}/2$=41.42 mm (element distance)

$dx_{Tx} = \lambda_{g\_Tx}/2$=43.995 mm

dy = 51.26 mm

(Wave-guide separation within each band, equal for both Rx & Tx arrays)

N_{Rx}=26 (number of elements/slots within each waveguide)

N_{Tx}=24 (number of elements/slots within each waveguide)

Slot width W = 3.00 mm

The slot data design was made for the active wave-guides fed by equal amplitude and phase. The passive wave-guides (the “other” band) were matched at the feed port.

The slot data obtained are shown in Table I:

Table I Wave-guide slot data

Vgl #	Slot displacement d (mm)	Slot length L (mm)	Calculated wave-guide impedance at centre freq.	Wave-guide height position (mm)	Slot separation along wave-guide (mm)	Rx/Tx - wave-guide
1	0.67	28.90	0.97 – j0.06	38.445	41.42	Rx
2	0.67	29.50	1.01 + j0.04	12.815	43.995	Tx
3	0.67	28.90	1.03 + j0.04	-12.815	41.42	Rx
4	0.67	29.50	0.97 – j0.07	-38.445	43.995	Tx

Figure 6 illustrates, in an illustrative embodiment, a set of interleaved wave-guides for transmission and reception. The wave-guides are here arranged symmetrically around a line through the centre of the extension of each wave-guide. Each wave-guide further comprises a number of slots n in each slotted transmitting wave-guide, while each slotted receiving wave-guide may have $n \pm x$ slots, where x then represents an integer digit, (e.g. 0, 1, 2, 3 ...). Such an array may typically be fed by means of active T/R-modules in order to reduce number of modules and consequently reduced cost.

<u>Simulations</u>

The simulated input impedance has been shown for centre frequency in the table above. From these simulations, the excitation ("slot field" amplitude and phase) was also extracted. This was used to calculate the antenna far field for the two main cuts, H- and E-plane. The "non-fed" wave-guides are terminated in a matched load. An antenna element model simulating a slot in a finite ground plane was used.

Figure 7 shows the radiation pattern when the Rx-wave-guides are fed with equal amplitude and phase. The corresponding case but with the Tx-excitations cleared (set equal to 0) is shown in Figure 8. It can be observed that for the two wave-guides alone for Rx, (Figure 7) grating lobes will appear in the

E-plane since the wave-guide distance is close to 1 λ. These lobes will be suppressed when the Tx wave-guides are present and parasitically excited, as illustrated in Figure 7.

The corresponding cases when the Tx wave-guides are fed with equal amplitude and phase are shown in Figure 9 and Figure 10

<u>Simulation of four element scanning array</u>

A simulation of a 4+4 element scanning array was also performed. The input impedance and radiation pattern was calculated at the Rx centre frequency, 5.671 GHz for the E-plane scan angles 0°, 10° and 20°. The simulation was made both with and without passive (terminated with a matched load), interleaved Tx wave-guides. The resulting radiation patterns are shown in Figure 11 to Figure 13. The wave-guide parameters are identical to the data shown in Table I above.

In a basic configuration according to the inventive configuration for obtaining a sparse array the inactive wave-guides i.e. receive wave-guides in a transmit operation and vice versa, could be given a favourable phase such that the sidelobe level will be decreased. When the array is scanned to a radiation angle off boresight an improvement will also be obtained by using such a technique and in both cases the array will became sparse compared to the standard case, thus a more simple and cheaper antenna having fewer active modules in an Active Electronically Scanned Array (AESA) achieved.

In a more simple version of the inventive configuration inactive elements can, for that particular moment, just serve as dummy elements interleaved between the active element by then being terminated in a suitable way. For instance a suitable shorting device or a matched load positioned at the proper position could then be used.

In a preferred embodiment of this sparse antenna configuration the idea is further based of having several pairs of long serial-fed transmission lines (not necessarily wave-guides) with many radiation elements connected in series and where the distances between the radiation elements of a transmit/receive pair can be somewhat different for the transmitting and receiving radiators, respectively. This will imply that a pair of antenna array columns become tuned to somewhat different frequencies and consequently very little power is coupled between their ports. Such series-fed antenna columns are thus for instance fed from a transmit/receive active module.

In another embodiment of the interleaved antenna array each radiator element of the respective series-fed antenna columns is narrowly tuned within a respective frequency band to thereby further reduce coupling between the transmitting and receiving frequency bands.

In still further embodiment only one set of series-fed columns are actively used, while the remaining set of interleaved set of series-fed columns are terminated by means of a suitable load. This could be used for an entirely tranceive type of operation using a common transmit/receive frequency.

It will be understood by those skilled in the art that various modifications and changes could be made to the present invention without departure from the spirit and scope thereof, which is defined by the appended claims.